

Cosmic Chemical Evolution 2010:

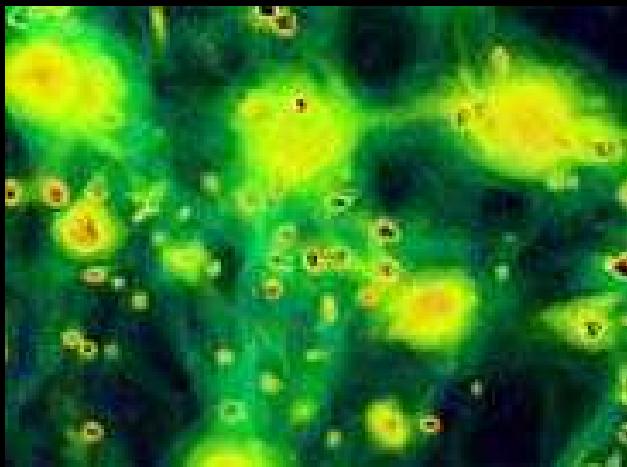
The Cosmic Star Formation History

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Clemson University

- CCE2010 Meeting : St Michael, MD -

Cosmic Chemical Evolution

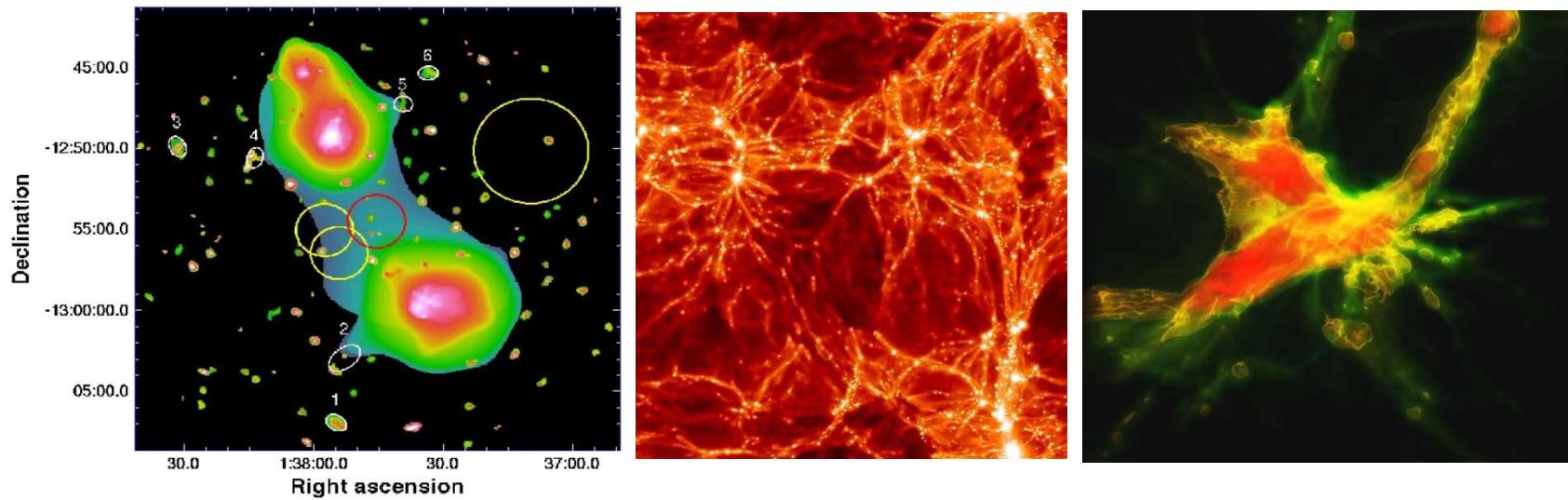


St Michaels, MA: June 2-4, 2010

- CCE is driven by SF
- Various Tracers
- SF in the Milky Way
- SF in the Universe at large

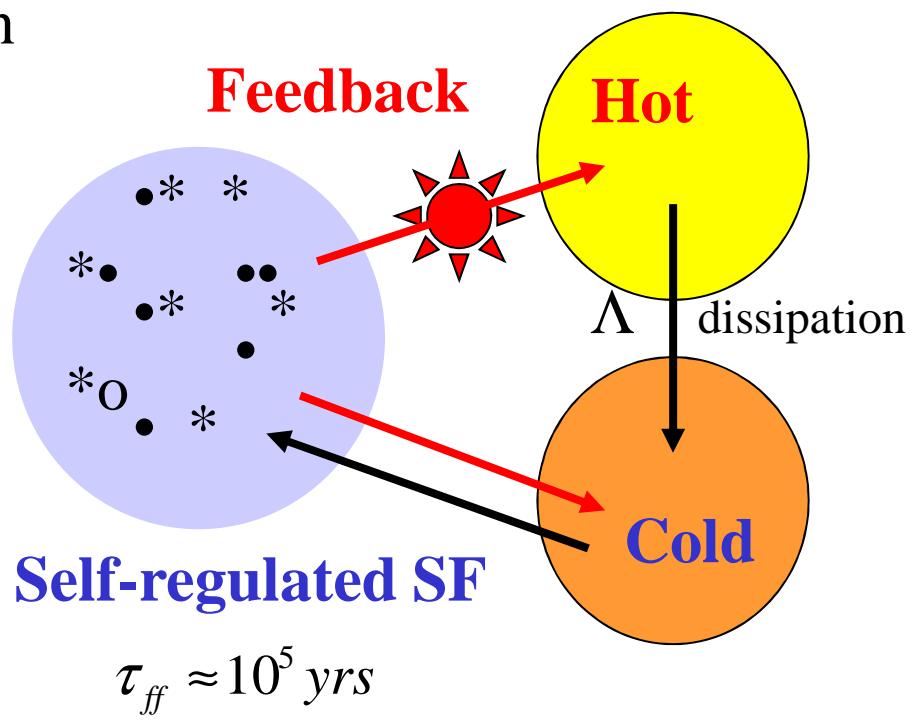
A few Implications:

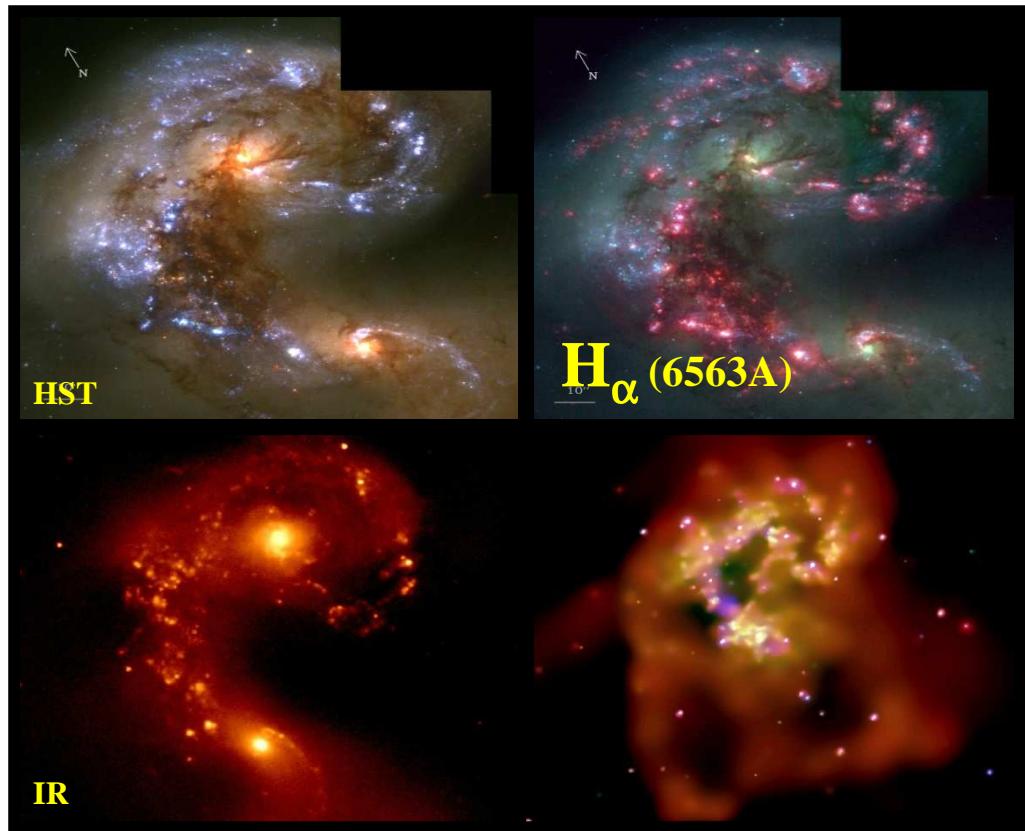
- Cosmic Gamma-ray Background
- Cosmic Neutrino Background
- Cosmic Opt/IR Photon Background
 $\rightarrow \tau_{\gamma\gamma}$ The opacity of the Universe



- Cosmic Chemical Evolution
- Galactic Chemo-Dynamics

$$\tau_{ff} \propto (G\rho)^{-1/2} \approx 10^8 \text{ yrs}$$





TRACERS

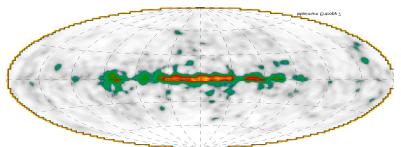
Continuum: Radio, **IR**, **UV**

Atomic Lines: **H α** , **H β** , **O II**,

Counts: OB*s, HII, PSRs, SNRs,..

SFR(SNR): IMF

AWR



$$SFR(M_{\odot} / \text{yr}) = 7.9 \cdot 10^{-42} L(6563A = H\alpha)(\text{ergs / s})$$

$$SFR(M_{\odot} / \text{yr}) = 1.4 \cdot 10^{-41} L(3726/9A = [\text{OII}])(\text{ergs / s})$$

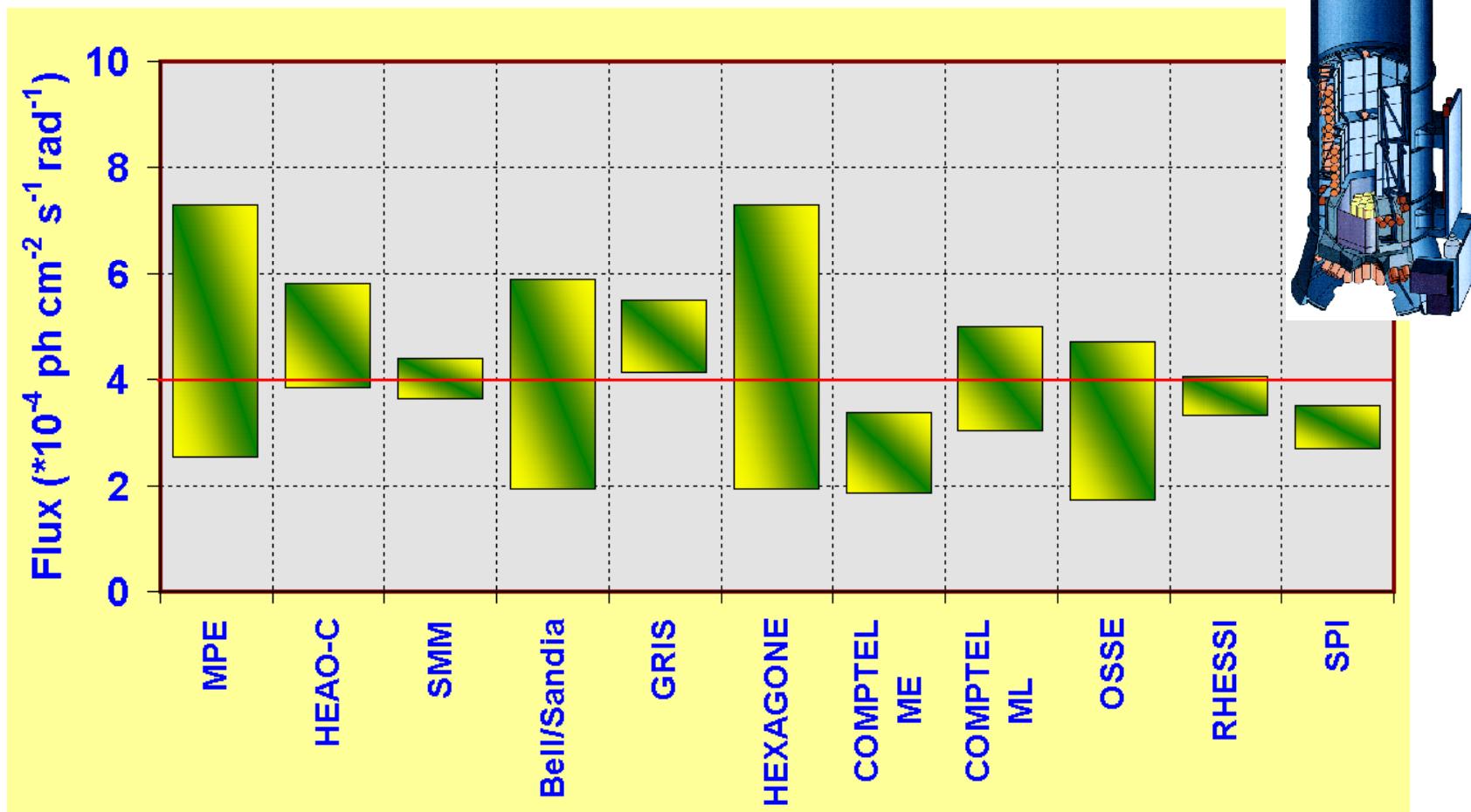
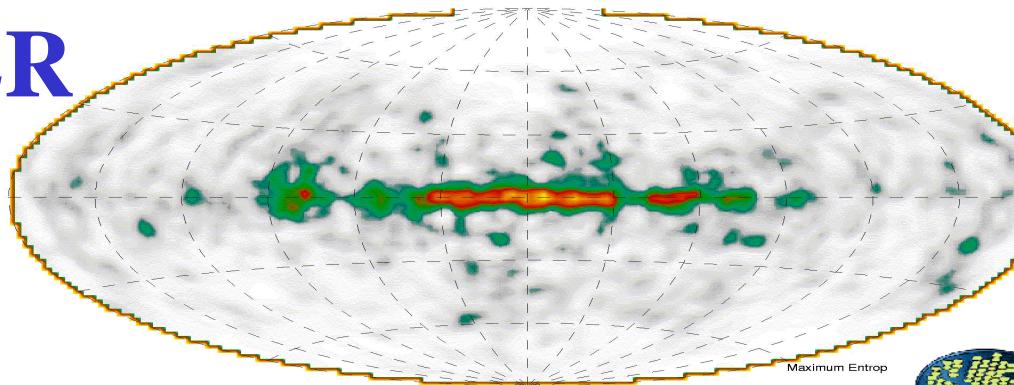
$$SFR(M_{\odot} / \text{yr}) = 7.9 \cdot 10^{-44} L(40-120\mu\text{m} = \text{FIR})(\text{ergs / s})$$

Kennicutt (1998) calibrations

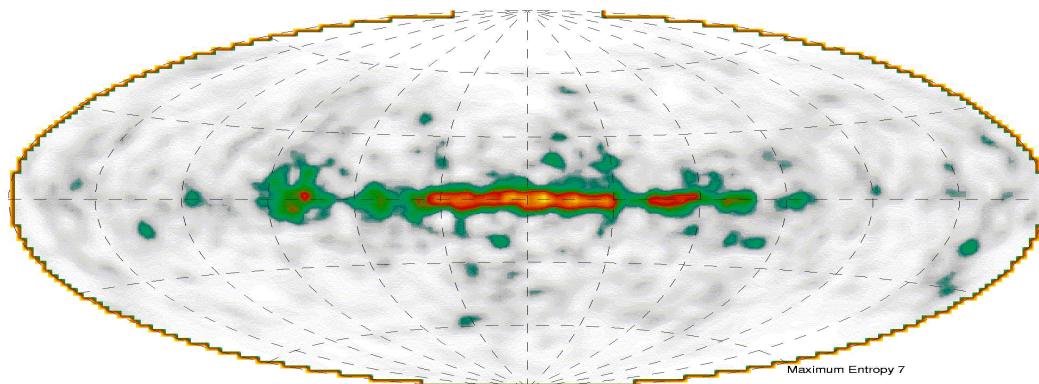
NEW TRACER

Radioactivities:

Lines: ^{26}Al , ^{60}Fe



^{26}Al , 1.8 MeV



$$SFR(M_{\odot} / \text{yr}) = 8.2 \cdot 10^{-5} f_{1.8} (\gamma / \text{cm}^2 \text{s}) D_{\text{eff}}^2 \eta_{\text{IMF}}^{-1} Y_{26}^{-1} \xi_{\text{novae}}^{-1}$$

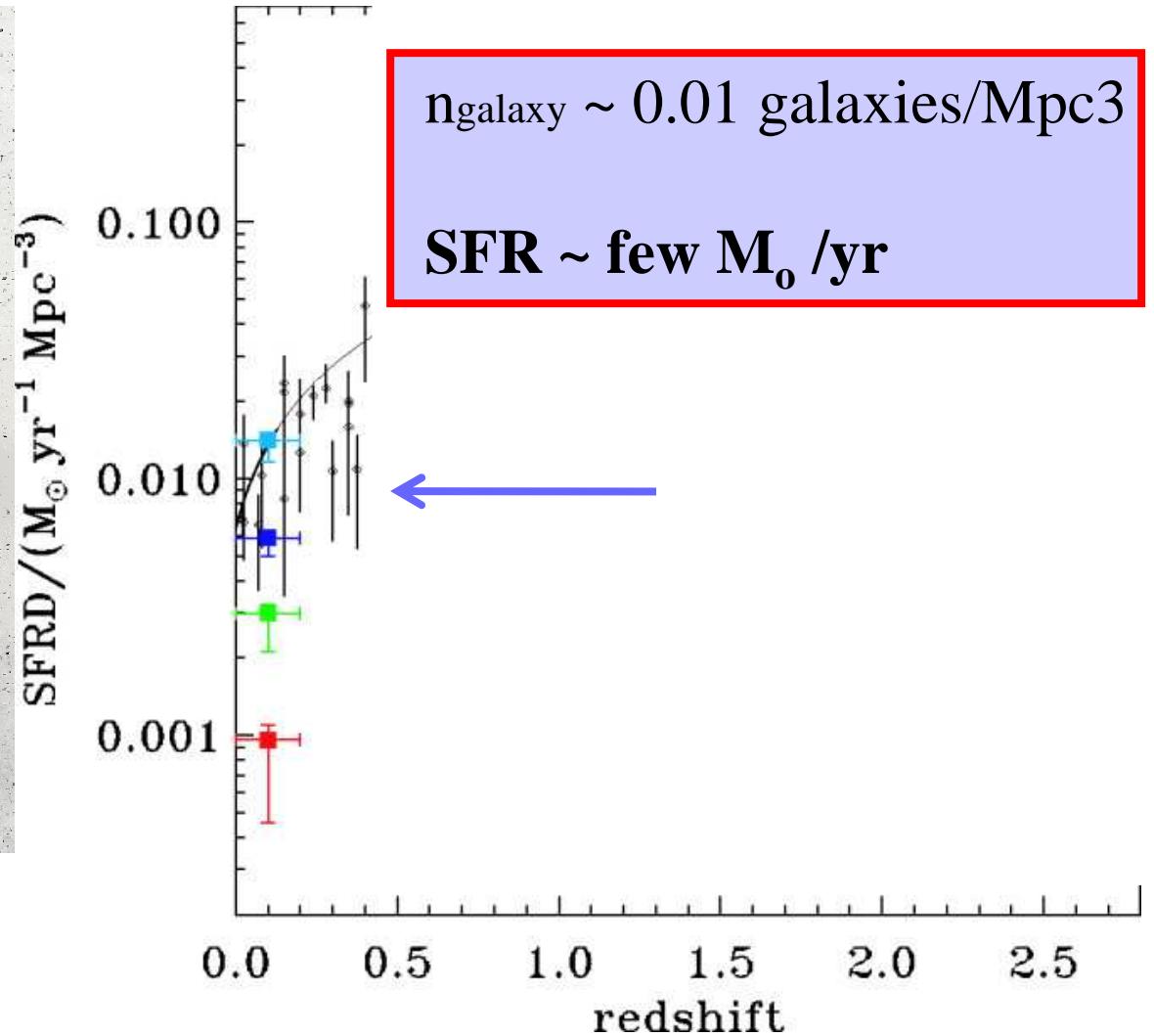
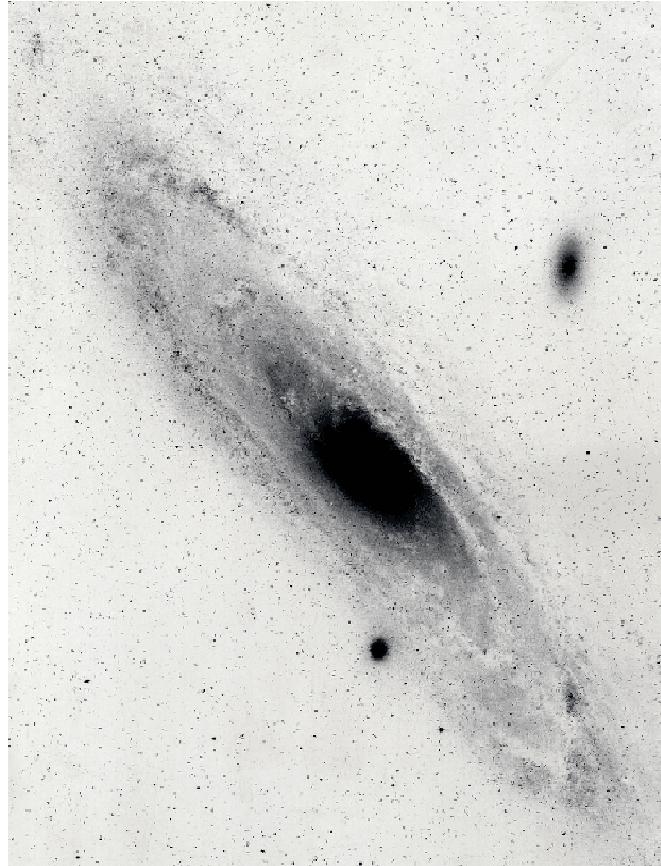
Observed flux ($\text{l} = \pm 30^\circ$) ($f_{1.8} \sim 3\text{-}6 \cdot 10^{-4} \text{ }\gamma/\text{cm}^2 \text{ s}$)

(COMPTEL=2.8±0.15, SMM=4.0±0.4, GRIS=4.8±0.8, SPI=3.3, RHESSI=5.7 ±0.54)

$\eta(\text{SNR/SFR}) \sim 10^{-2}$, $Y_{26} \sim 10^{-4} M_{\odot}$, $\xi = 1$, $D_{\text{eff}} = 8 \text{ kpc}$ → **SFR ~ few M_{\odot}/yr**

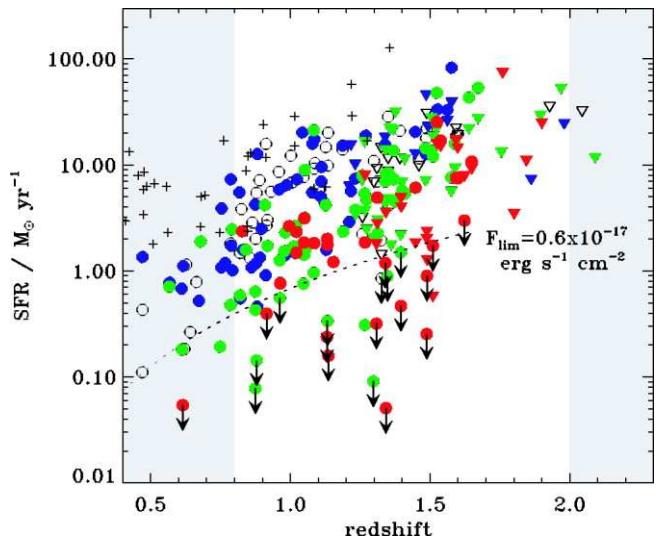
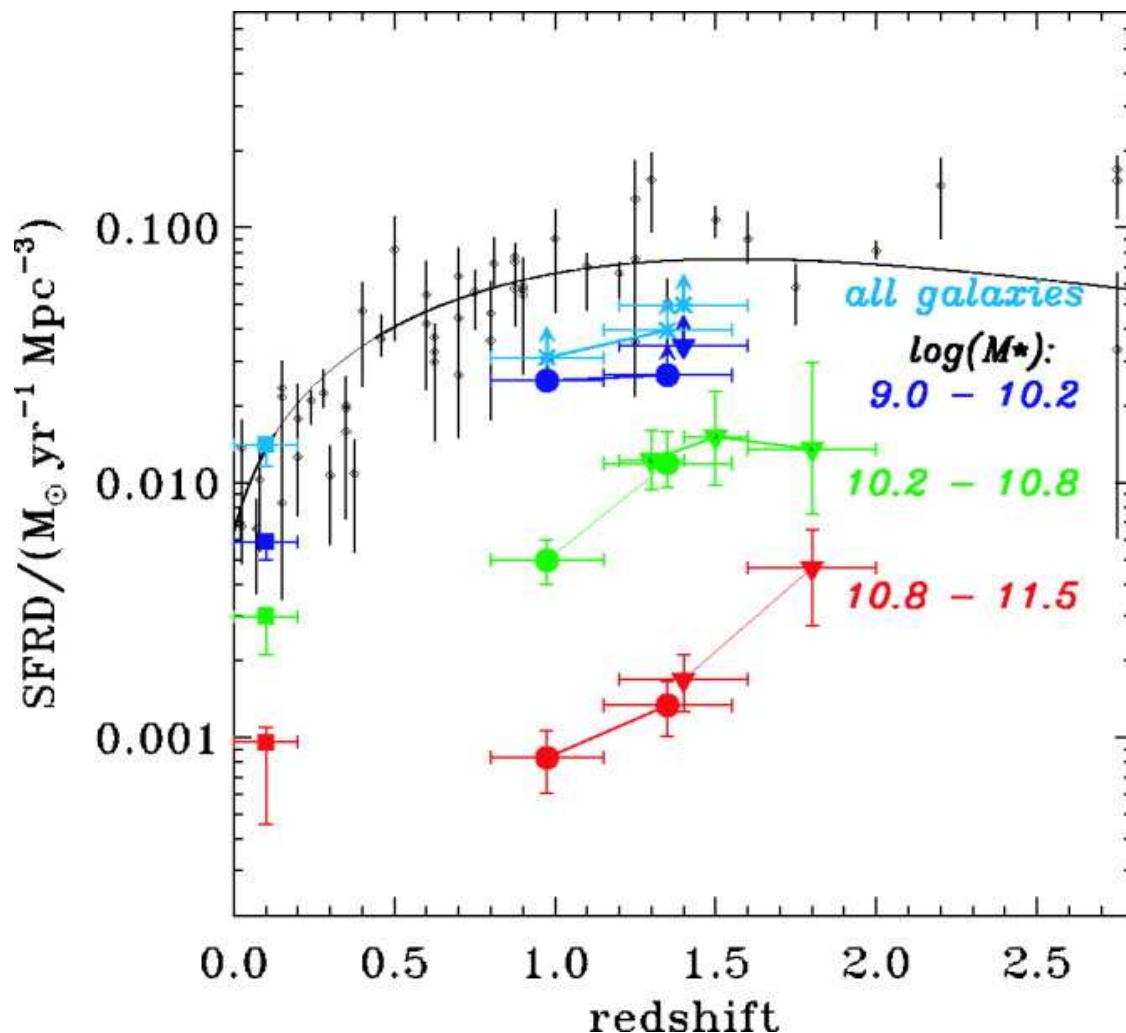
The SNR-SFR conversion is sensitive to the IMF and yield estimates.

The local star formation rate density



Gemini Deep Deep Survey

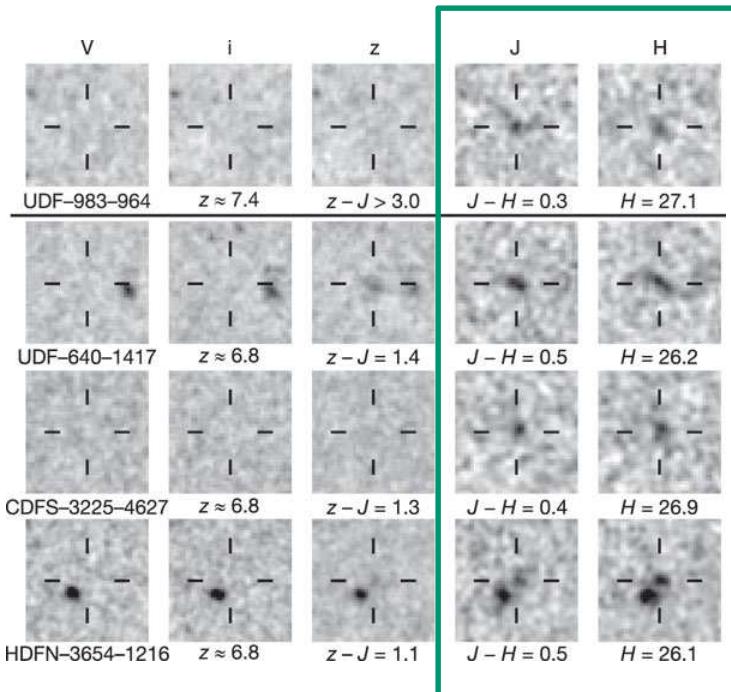
[OII](3727)A luminosity
Rest frame UV cont. ($Av = 1$)



Juneau, S. et al. et al. 2005, ApJ
Galaxy-Mass-dependent SFR

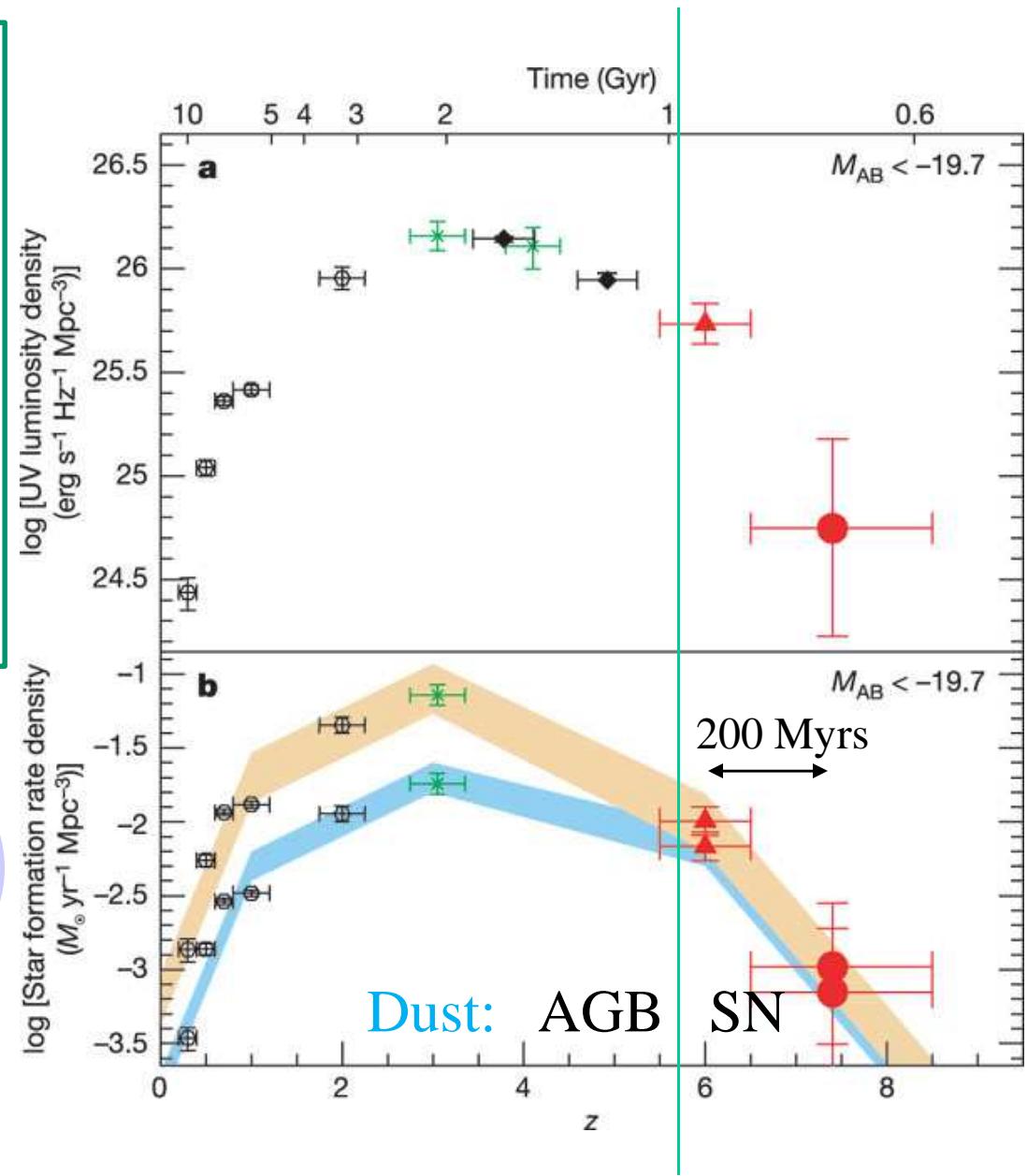
● L([OII])
▼ L(UV cont. (2000A))

Bouwens, Illingworth 06...: Deep NIR NICMOS (HUDF): z dropouts



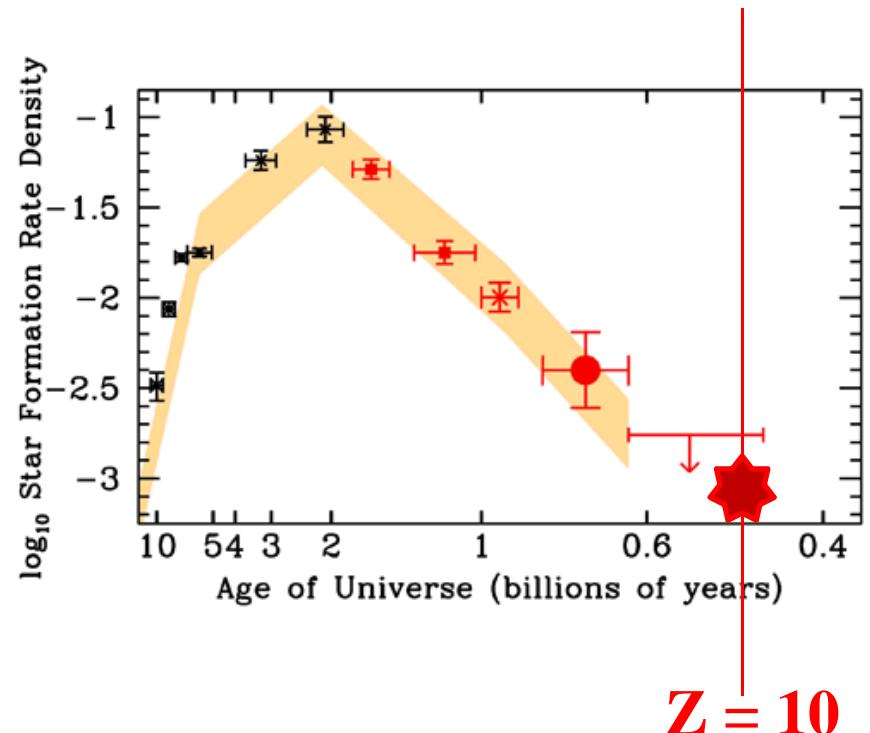
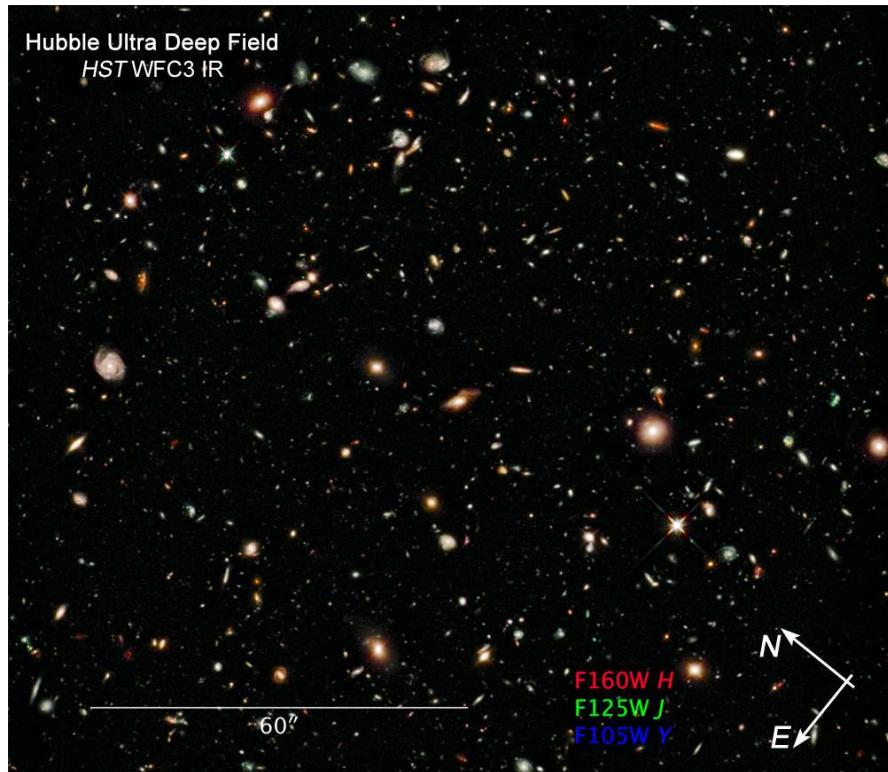
How do we find and
probe $M_{AB} > -20$ galaxies?

GRBs as signposts



Bouwens et al. 2010, Nature, sub.

3 J-dropout candidates at $z = 10$

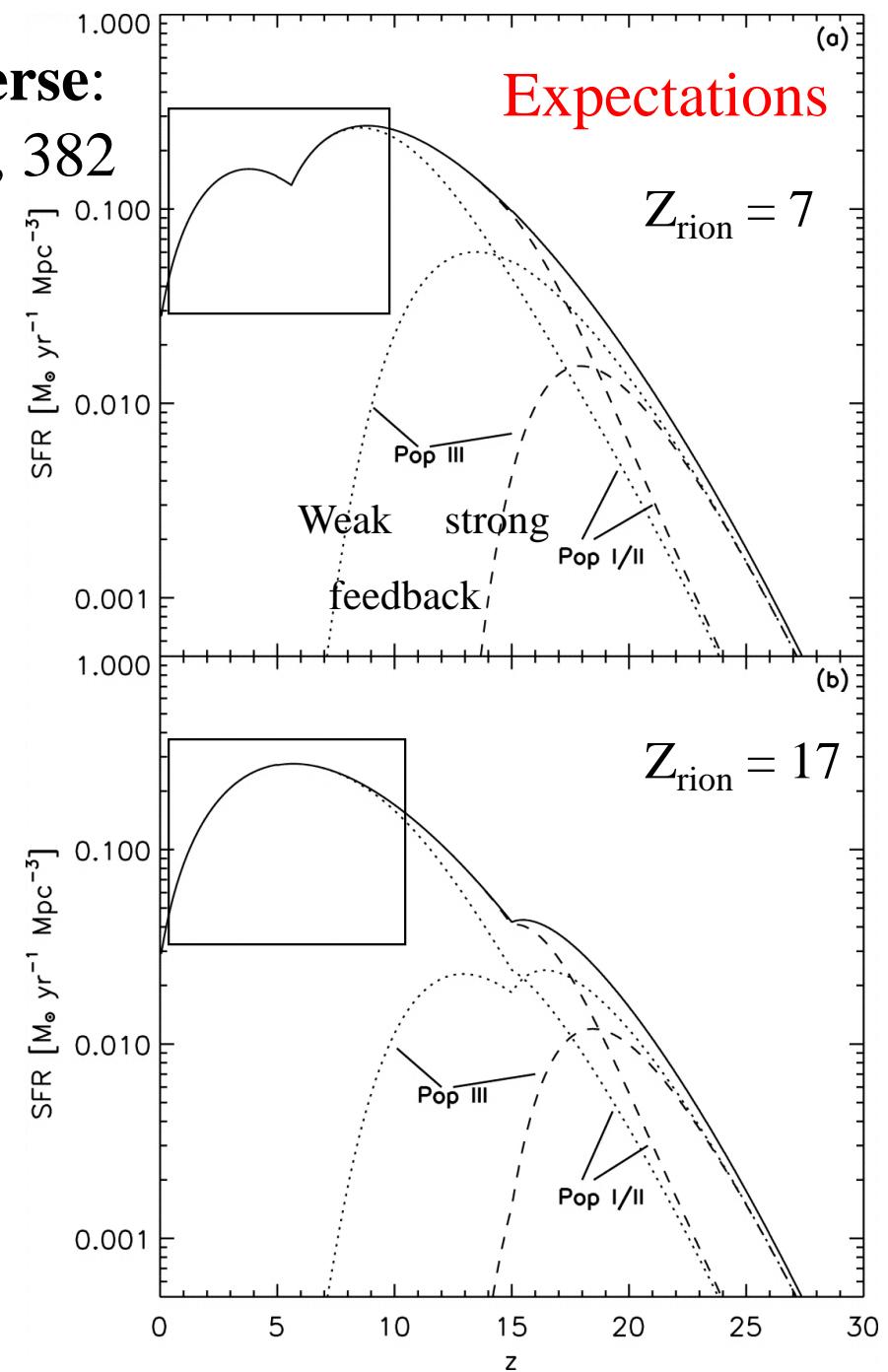
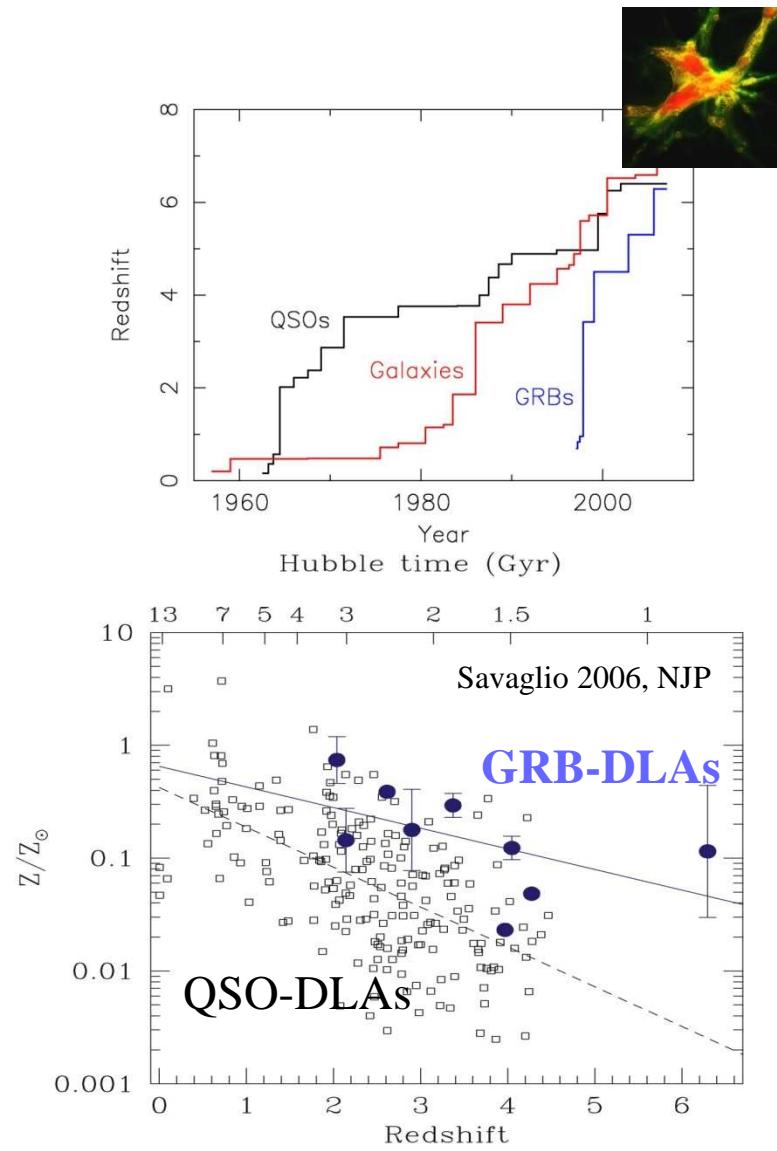


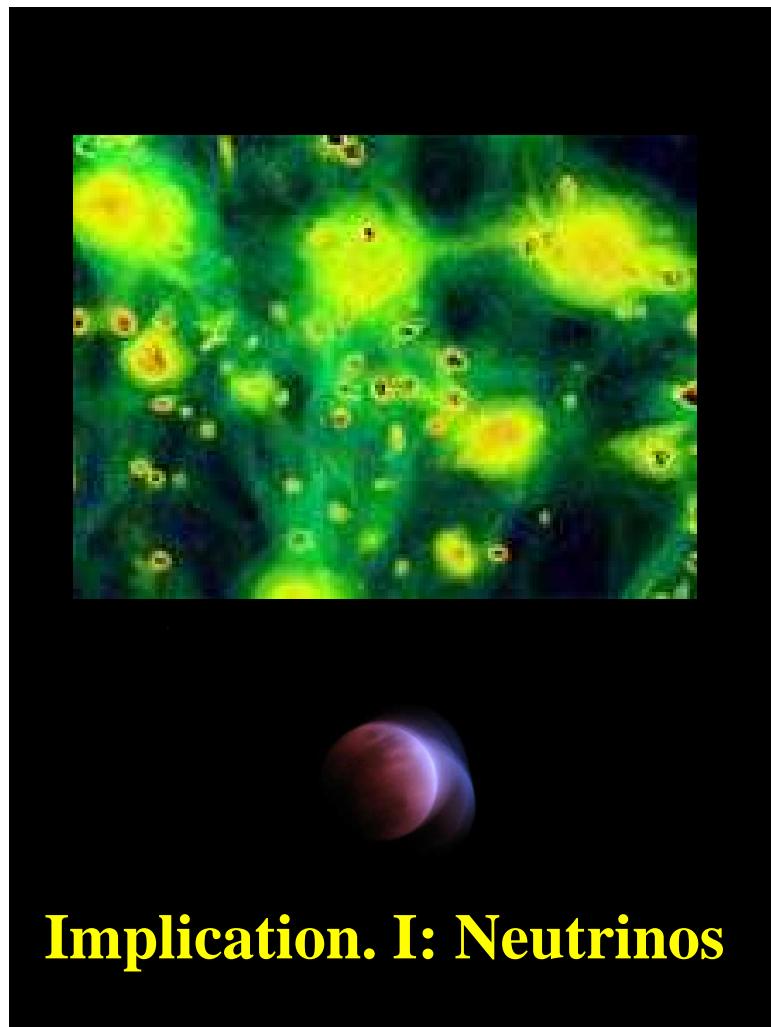
UV evolution continues to $z = 10$.

These galaxies provide 25% of what is required for reionization.

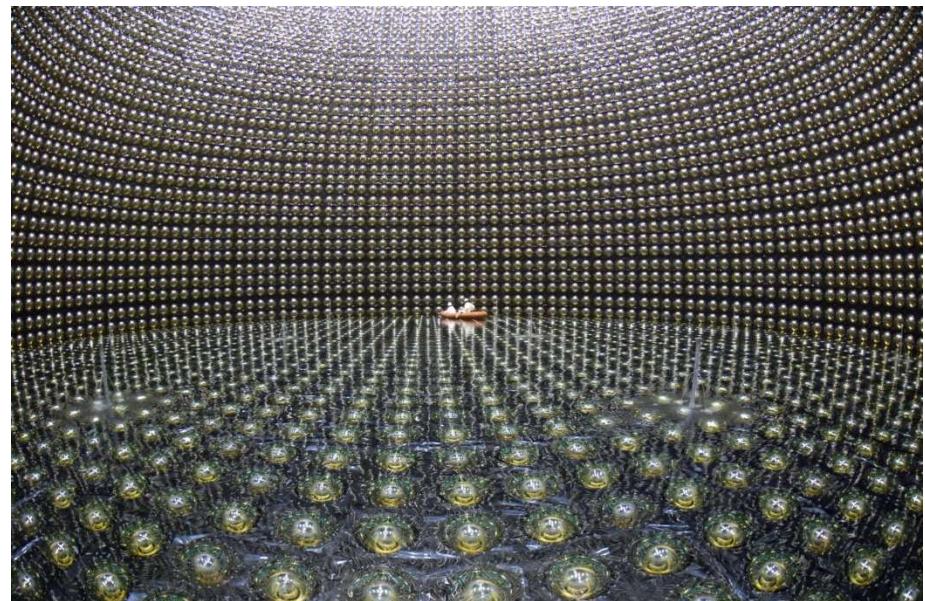
Star Formation in the Early Universe:

e.g., Bromm & Loeb 2006, ApJ 642, 382





Implication. I: Neutrinos



Super-Kamiokande



Sanduleak $-69^{\circ} 202$

SN 1987A

D ~ 50 kpc

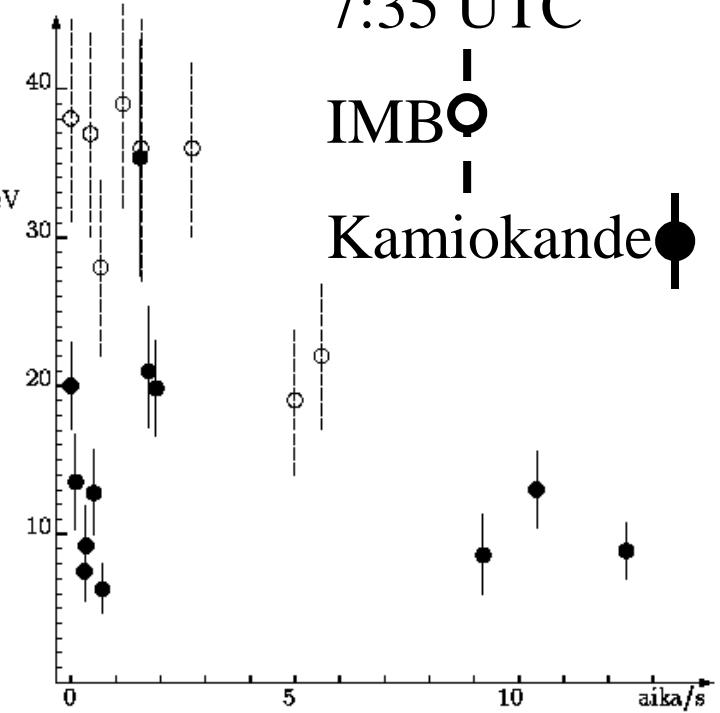
ν -burst !

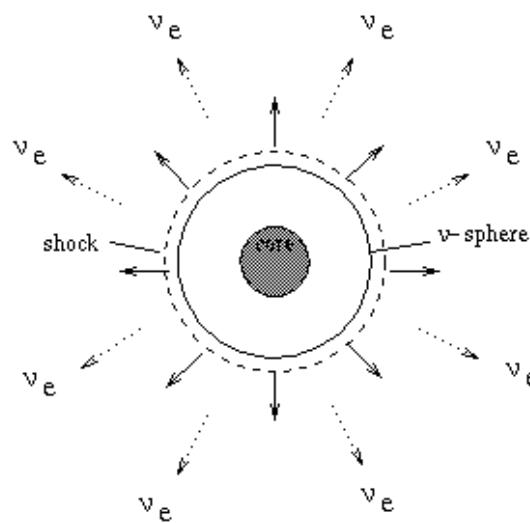
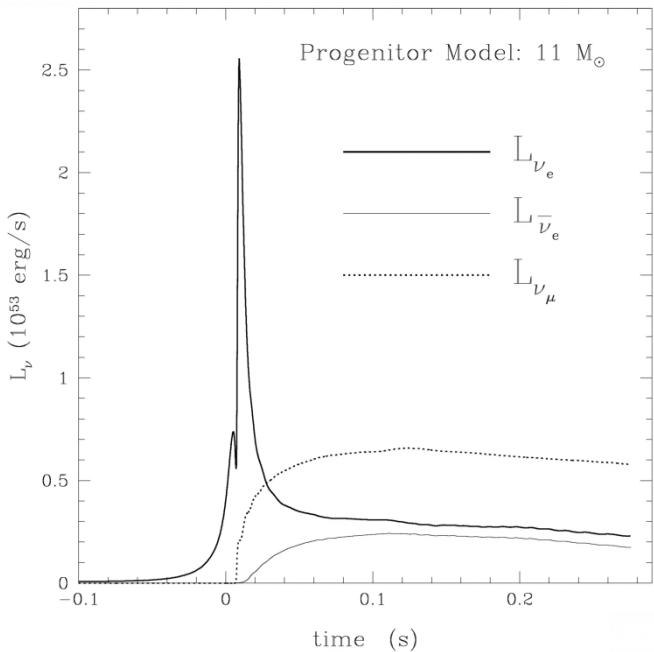
Feb 23, 1987

7:35 UTC

IMB

Kamiokande



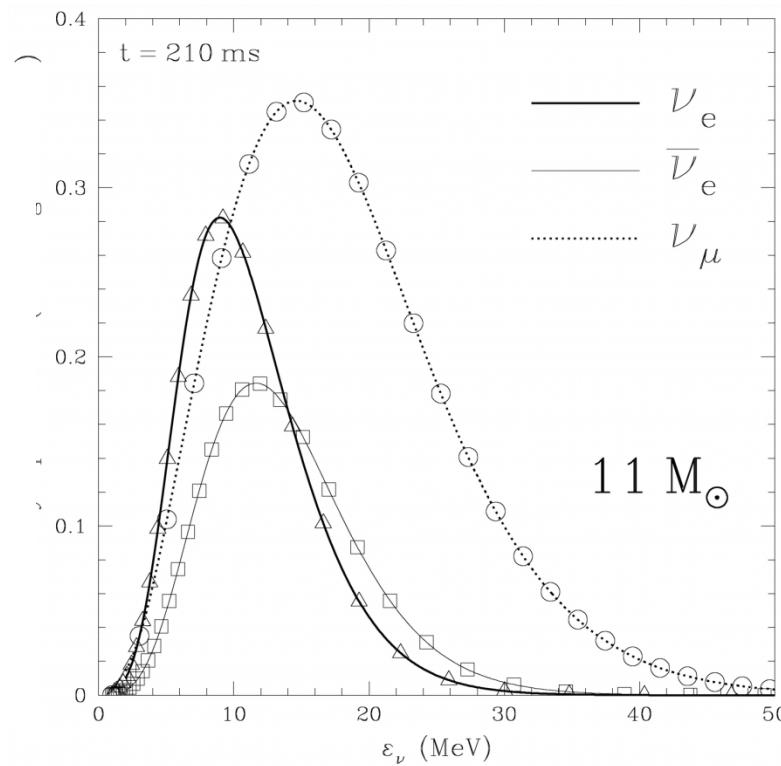


Thompson, Burrows, & Pinto 2003, ApJ 592, 434

also: Keil, Raffelt, & Janka 2003, ApJ 590, 971



$$\varepsilon_{\nu\mu} > \varepsilon_{\nu e} > \varepsilon_{\bar{\nu} e}$$



$$\varepsilon \sim \pi k T_{\nu}$$

$$F(E) \neq FD$$

Guseinov 67

Bisnovatyi-Kogan, Seidov 82

Domogatskii 84

Krauss et al. 84

Bisnovatyi-Kogan, Seidov 84

Lagage 85

Dar 85

Woosley et al 86

Schramm et al 86

Totani et al 96

Malaney 97

Hartmann & Woosley 97

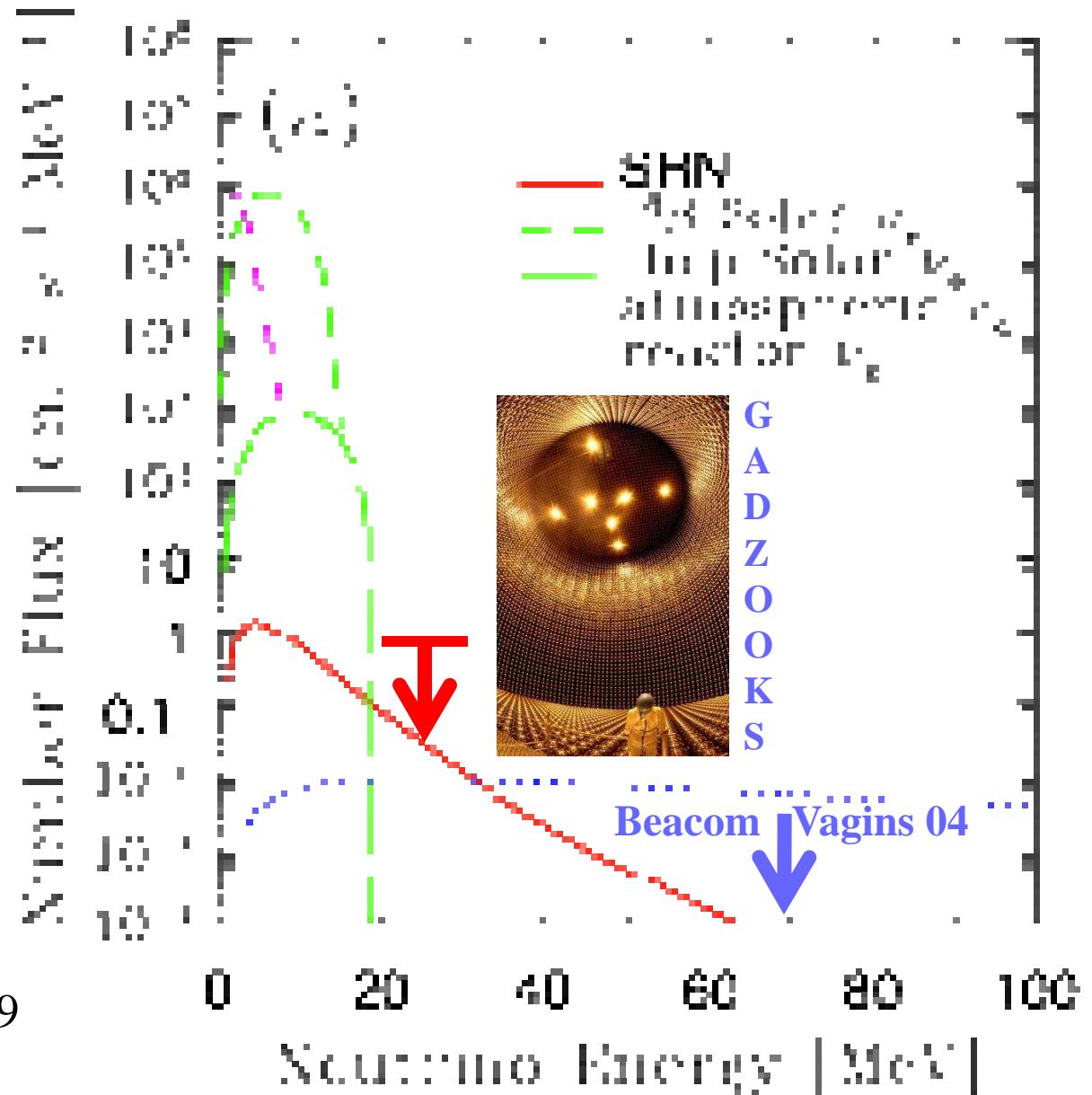
Kaplinghat et al 2000

Ando et al 2003

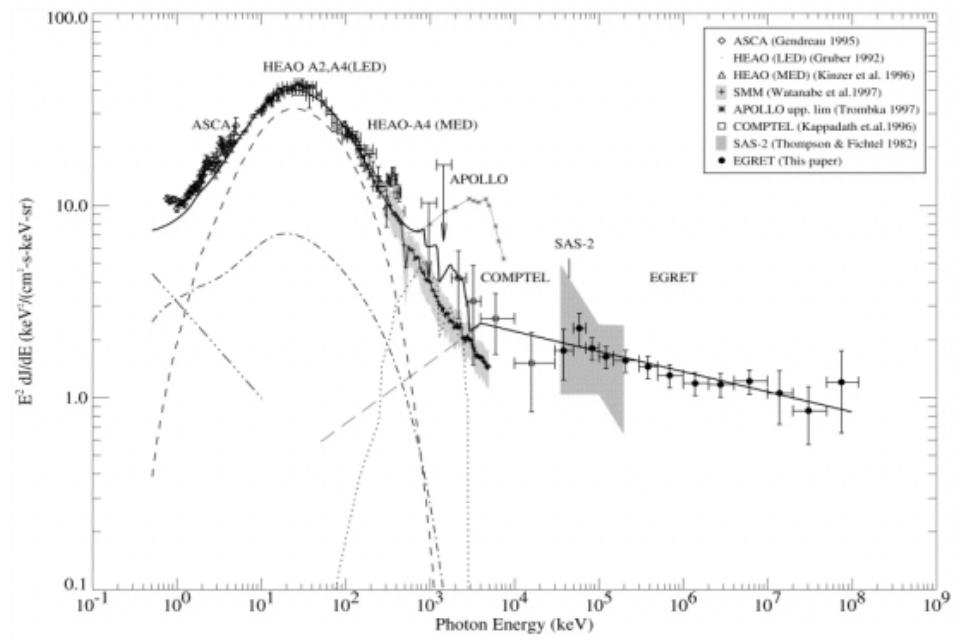
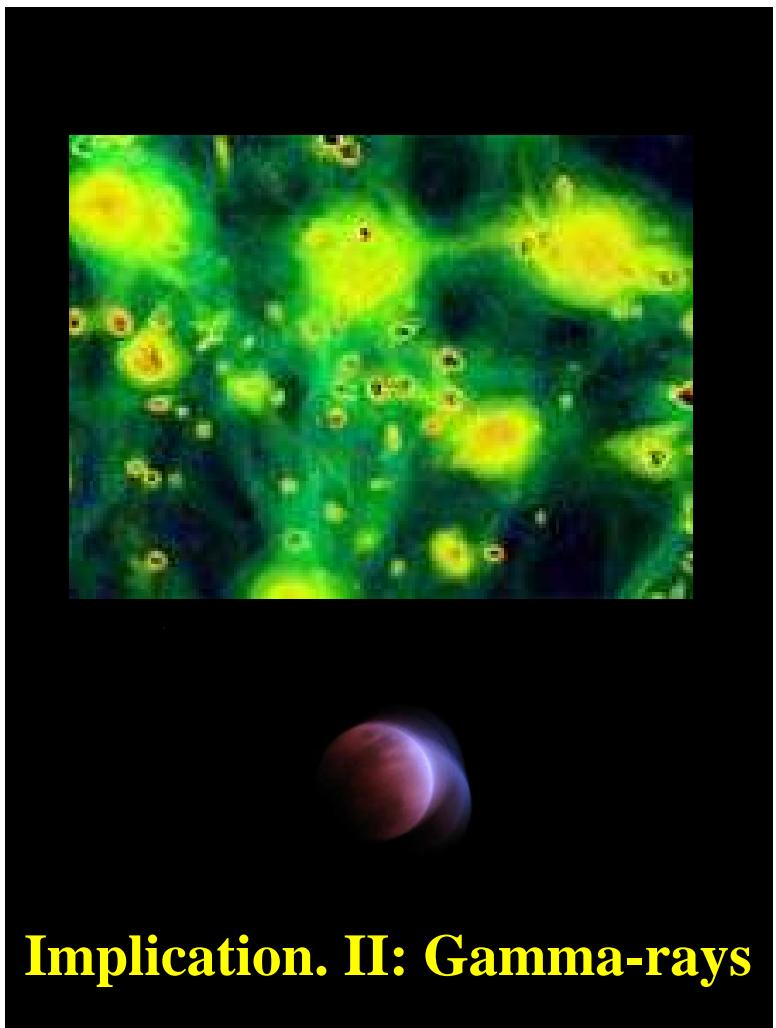
....

Beacom, Strigary, Kistler,

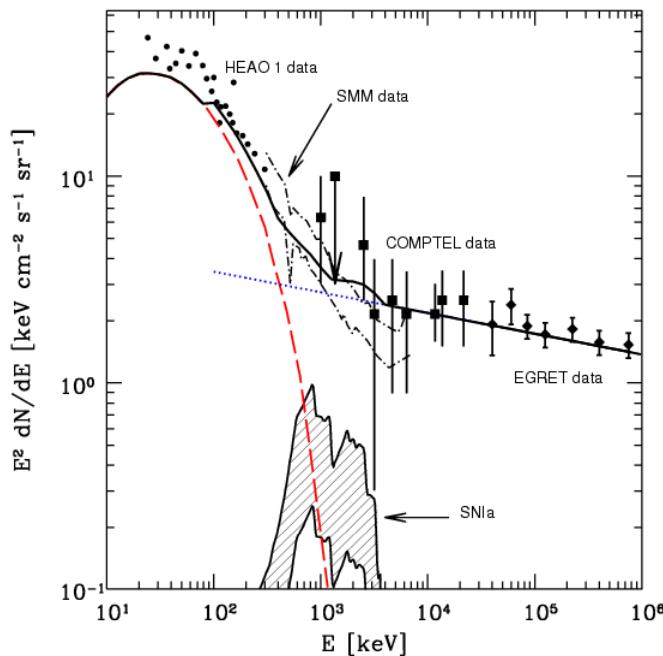
Horiuchi, Beacom, Dwek 2009



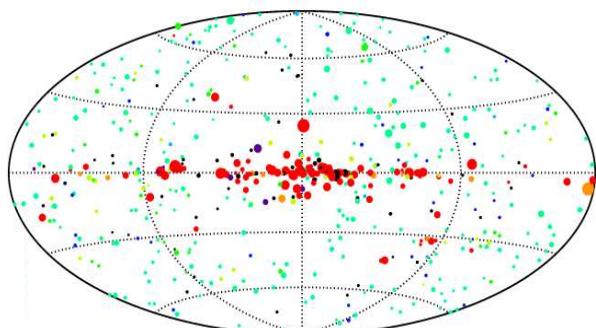
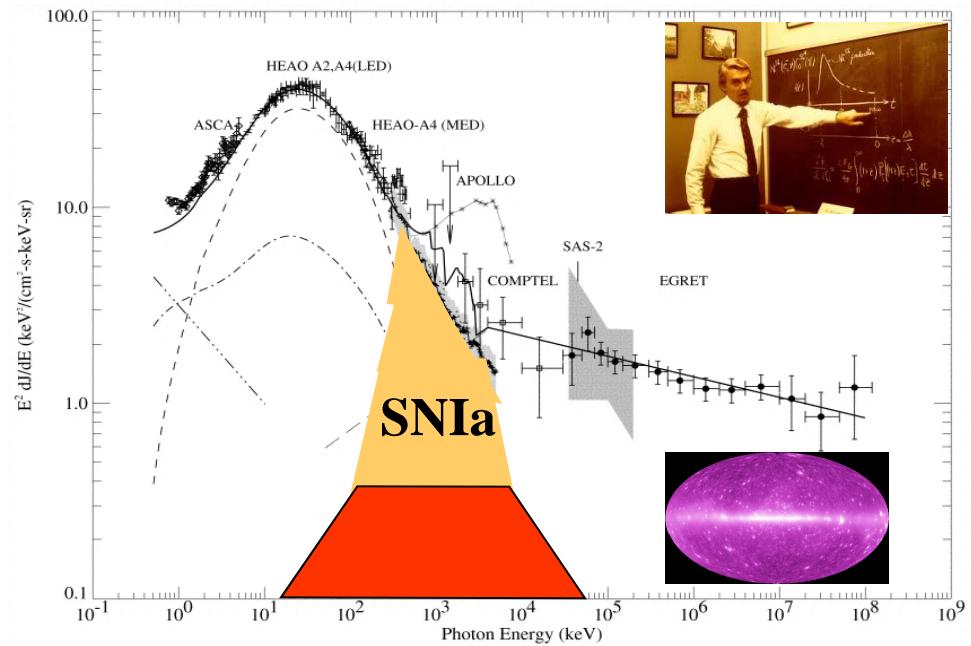
SK limit ($E > 19$ Mev): Malek, M. et al. 2003, PRL 90:061101 : **1.2 /cm² s**



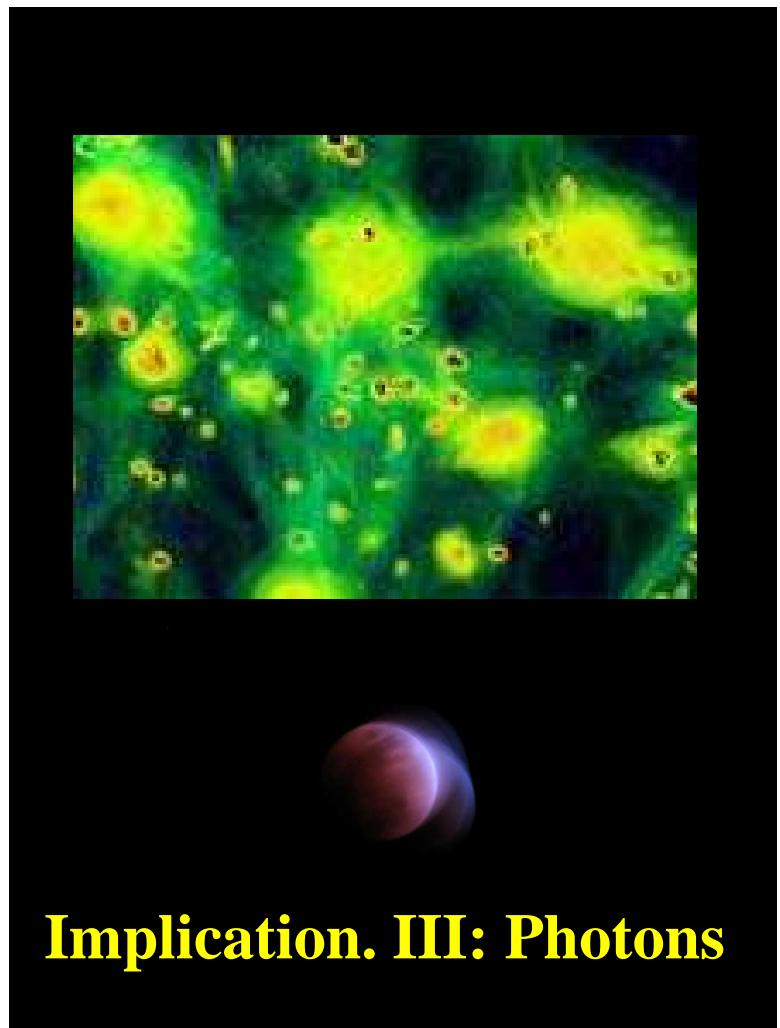
The γ -ray Background



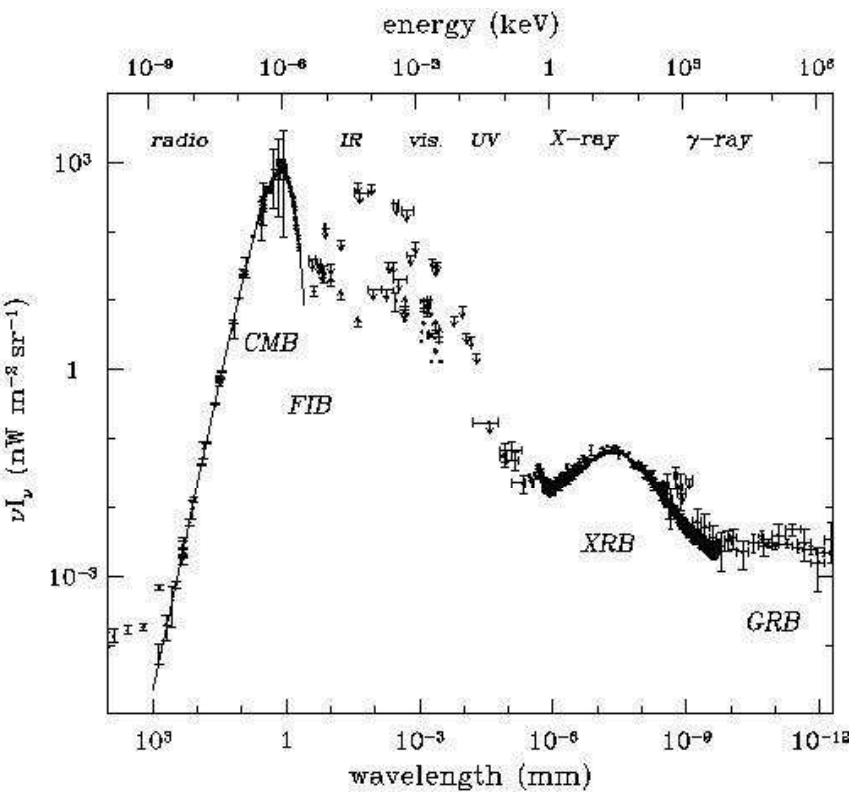
CGB (^{56}Co): Clayton & Silk 1969, ApJ 148, L43



Swift/BAT:
M. Ajello, et al 2009, arXiv:0905.0472
FSRQs can explain the entire MeV bkgnd

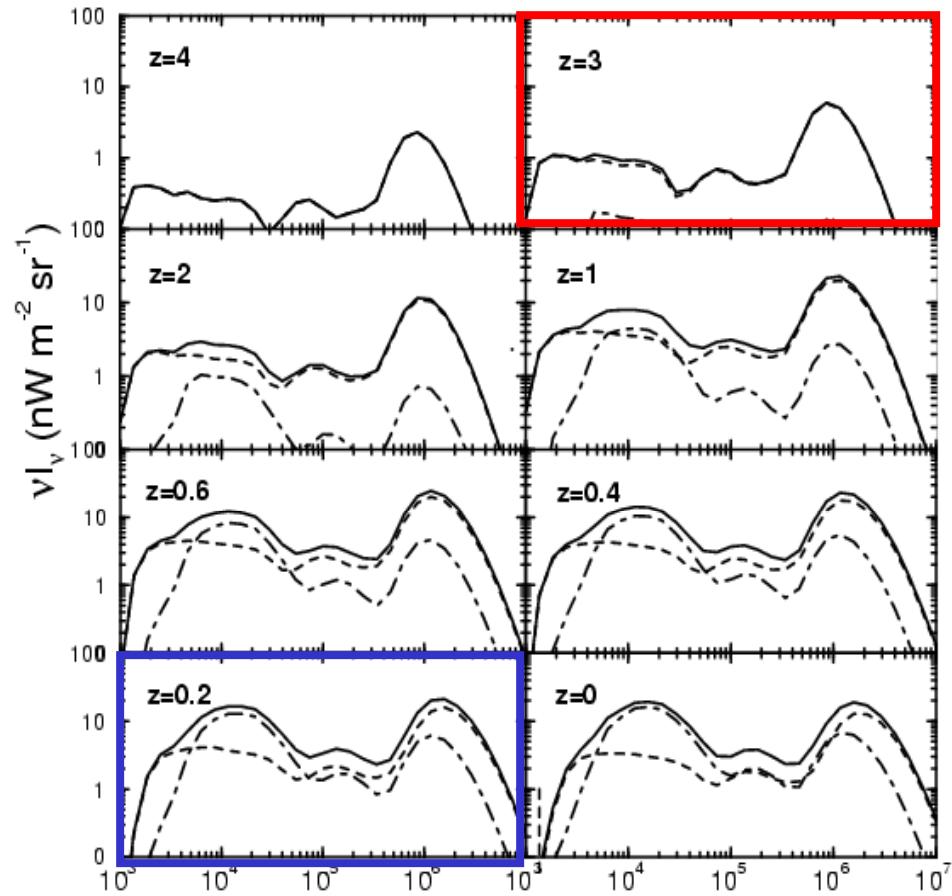


Implication. III: Photons



Reprocessing of light

The metagalactic UVOIR background

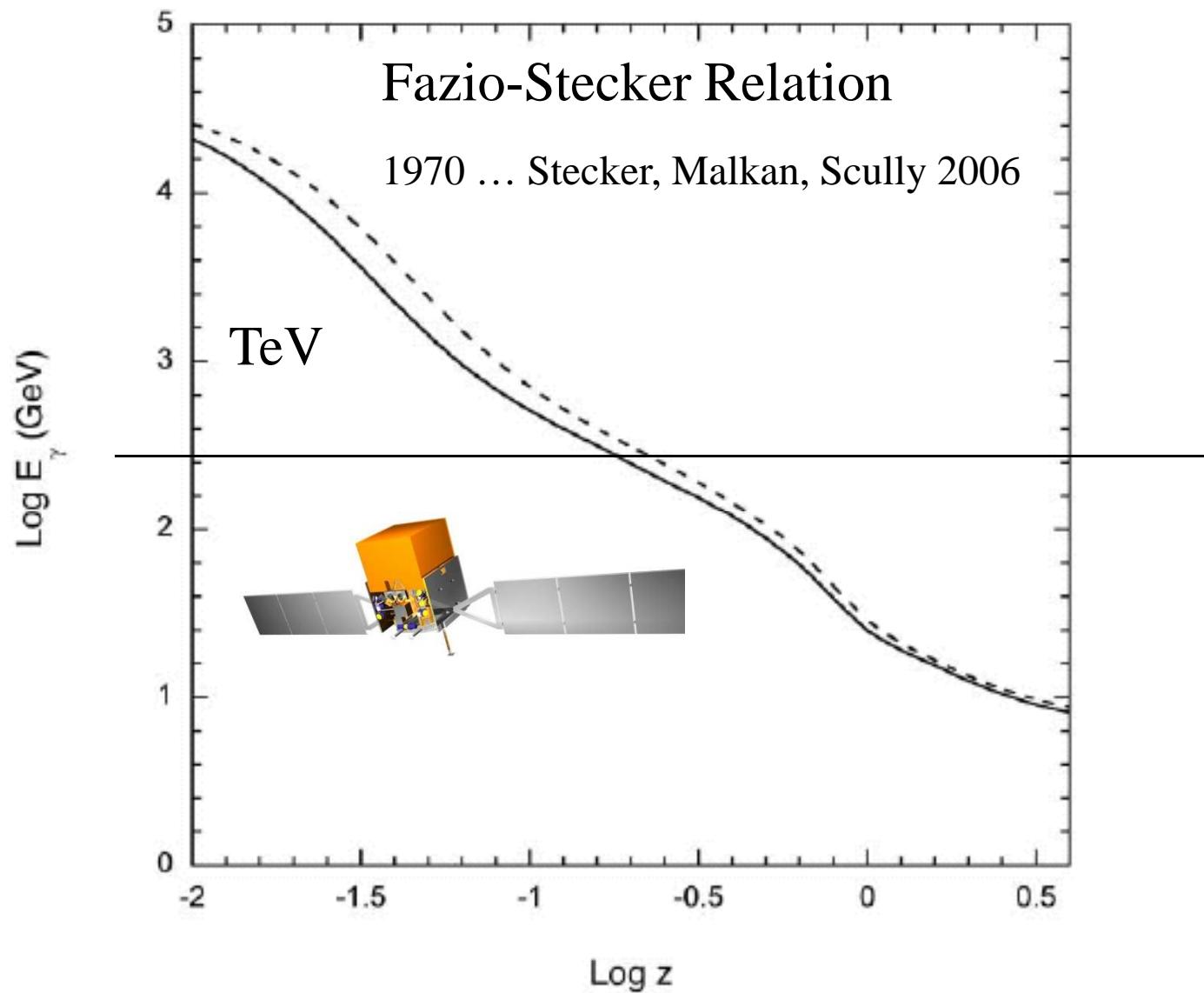


Kneiske, Mannheim, Hartmann. 2000 A&A 386, 1

Tinsley 1977, ... Madau, Primack, Fall, Pei, Dwek, Krennrich, Malkan, Stecker, Scully,



The gamma-horizon: $\tau_{\gamma\gamma} = 1$



CCE - SFR(z)

- Cosmic Gamma-ray Background
 - Cosmic Neutrino Background
 - Cosmic Opt/IR Photon Background
- $\tau_{\gamma\gamma}$ The opacity of the Universe

The End